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A USER-ORIENTED APPROACH TO PERCEPTION OF HUE CONTRAST ON THEMATIC MAPS

by

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled A USER-ORIENTED APPROACH TO PERCEPTION OF HUE CONTRAST ON THEMATIC MAPS, submitted by Charlette Kay Campbell in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

In this study color, although poorly understood in its effect, is identified as a viable method of presenting information on maps. Cartographic utility of color and problems of usage in the contextual sense of visual information retrieval are discussed. The focus is specifically on the problem of color contrast with special attention given to hue, one of the three parameters of color. It is suggested that color contrast cannot be objectively studied until the effects of each color parameter are understood.

An experiment, designed for easy replication, attempts to examine perceived difference in hue contrast and "organization" of the symbol under the simulated conditions of a map reading situation. While subject response to fourteen colored dots on a colored background is largely contingent upon strict regulation of lightness and chroma, great care is taken in standardizing viewing time and illumination. It is under the condition of limited time exposure that perceived differences in colored symbol recognition can be easily quantified. Results of the study, which involves testing six hundred subjects, indicate that few combinations of colored symbols on colored backgrounds, being equal in lightness and chroma, are perceived as measurably different in contrast effect. From this finding it is inferred that hue is not an important factor in producing differences in color contrast, but some significant differences do exist between hue combinations. Presence of "organization" cannot be conclusively determined. Results are evaluated in terms of Koffka and Harrower's (1931) theories.

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There is no such thing as a perfectly faithful model; only by being unfaithful in some respect can a model represent its original.

M. Black (Models and Metaphors)

INTRODUCTION

Color on Maps

Color plays an important part in the transmittance of a cartographic message by creating effective differences in legibility and emphasis on maps. More specifically, color can be used to attract attention, develop associations, build retention, create an aesthetically pleasing display, and produce psychological reactions (Turnbull and Baird, 1968). With greater freedom of communication thus provided the map maker, color is now regarded as an indispensable element in cartography. Robinson (1952, p. 76) writes:

> It is now considered so important that the making of a map without color is a kind of negative undertaking, that is to say, a black and white map is usually constructed because color could not be used.

While color on maps has many advantages, determining an appropriate color scheme complicates the cartographer's task. Confusion in selecting colors is primarily the result of insufficient knowledge concerning the effects of color on the map user. Too often the final map-product does not convey the intended ideas. Consequently, the reader spends much of his time and effort on identification and interpretation of the color symbols and less time absorbing the total content of the map.

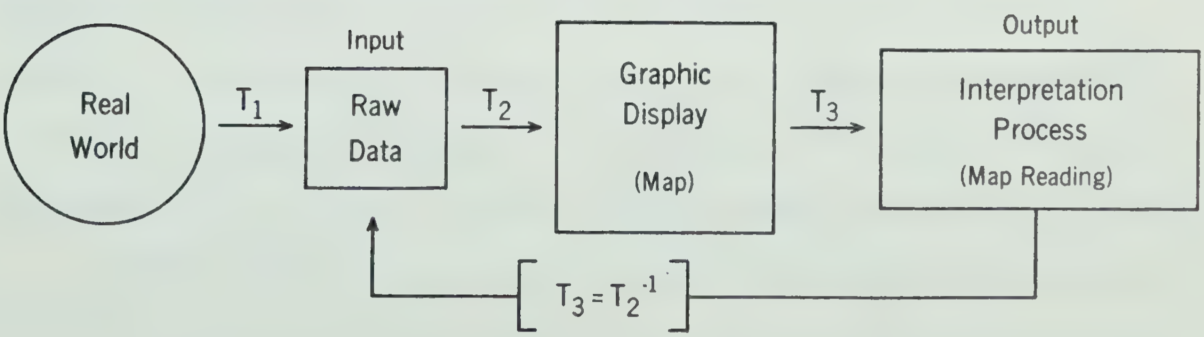
Establishing guidelines for color usage on maps is a complex problem. Cartographers have found that the task is more difficult than assigning a color to a particular feature. Color selection is slightly different for topographic and thematic maps (also called special purpose

or statistical maps). Selection of color for topographic maps is restricted by color conventions, whereas more freedom of color choice exists in designing thematic maps. However, for both map types, difficulties may arise when standard colors, for example blue for water or red for large urban areas, are placed in juxtaposition to other colors. Many times blue and red conflict with the planned emphasis or aesthetic requirements of the map by reducing the effective enhancement of other colors or reducing the total artistic impact. Colors selected arbitrarily or intuitively without due regard for the purpose of the map may be inconsistent with the inherent and learned limitations of the human perceptual mechanism.

As a means of analyzing the problem of color usage, communication theory provides a generalized picture of the cartographic system. This theory, although complex, can be diagramed (Figure 1) in cartographic terms as a series of transformations.

Figure 1

CARTOGRAPHIC SYSTEM



Source: P. Muehrche, 1969, p. 2.

As Muehrche (1969) explains, the researcher selects data from the real world (T_1). The data is then transformed by the cartographer into a graphic display (T_2). Final output is the information extracted from the graphic display through psychophysical[1] processes involved in map interpretation.

In applying communication theory to the problem of color usage, the cartographer hopes to find appropriate colors (T_2) which equal the map user's informational output from T_3. A more realistic view of perceptual response is where $T_3 = T_2^{-1}$. This last equation expresses the concept that the limitations of the human perceptual mechanism inhibits total information retrieval. Even then T_3 will not equal T_2^{-1}; perceptual response is not within the scope of exacting measurement. In a cartographic system, T_3 and T_2^{-1} will only approach equality.

To solve the problems of color usage, greater emphasis should be placed on investigation of the human perceptual stage (T_3) rather than T_2. That is, research in color usage should focus on the map reader. Analysis of behavioral response to color seems more efficient than trial and error preparation of colored maps.

<u>Problem</u>

The present research, employing a communication theory approach, attempts to investigate the map user's perception of color contrast. Contrast is a perceived difference in sensation. The visual mechanism (a function of eye and mind) tends to accentuate differences in colored justaposed objects in space and time (Burnham, Hanes and Bartleson, 1963).

Color contrast is attributed to three dimensions of color, <u>hue</u>,

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[1] Psychophysics in the study of the relations between sensations and the stimuli that produce them.

lightness and chroma, which the eye receives simultaneously. Among the disciplines of colorimetry, art and psychology, there exists a variability in the definition of hue, lightness and chroma. However, in view of the approach taken in this study, the following psychological definition of the three color dimensions (Judd, 1951) will be adopted:

> Hue - the sensation of color quality which makes a color distinctive from other colors. A direct function of wavelength, hue ranges from violet, through blue, green, yellow, orange to red.
>
> Lightness - the sensation of light reflected from a hue. Every hue has a value rating and can be matched with one of the tones on a gray scale from white to black. The terms brightness and value are often used in place of lightness. Brightness, however, is more correctly applied to self-luminous objects such as colored light rays.
>
> Chroma - the sensation of strength or dilution of hue. Also called saturation, intensity, and purity, chroma is varied by changing the ratio of gray and hue while maintaining a constant value rating. A scale of chroma ranges from pure hue to a neutral gray.

This study will focus on hue as a contributing, but artificially isolated, factor in color contrast on thematic maps. Present conventional color usage on topographic maps restricts direct application of changes in color schemes. Differences in contrast ability of various hue combinations will be evaluated by testing numerosity discrimination (defined by Stevens (1951) and Lechelt (1971) as a response to the numerical property of an array of objects which can be distinguished without counting) of colorant stimuli presented in a simplified map situation.

Measuring the numerosity response to a graphic display of colored symbols is considered an appropriate method of evaluating the map reader's ability to discern differences in hue contrast. Muehrche (1969, p. 74) states that "... the goal of the [cartographic] researcher

should be a test design that most closely approximates the actual map interpretation process." Since striking differences in contrast between a colored symbol and colored background facilitate accurate discrimination of the number of symbols, variation in numerosity response would indicate perceived differences in color contrast.

Previous Studies

In cartographic literature, hue, as an effective element of color contrast, is not extensively discussed. Research on hue contrast has been neglected and other elements of color contrast, such as lightness, have been examined instead. Among the few cartographers who have investigated the problem of color contrast, Keates (1962), Robinson (1967), and Wood (1968) generally agree that lightness, and not hue, is the most influential factor in producing effective contrast. Robinson (1967, p. 54) clearly states:

> The effect of value contrast upon the ability of the eye and mind to distinguish, perceive, or read cartographic detail is probably the single most important element in cartographic design, when the objective is to communicate.

The validity of Robinson's statement is not questioned here, however, his statement indicates the level of development to which cartographic research in color perception has progressed. That is, cartographers are still at the <u>theoretical</u> stage of examining color contrast. Discussions on perceptual effects of hue, lightness, and chroma appear to have no empirical grounding other than upon the experimental results drawn from outside disciplines. This is not to deny that cartographers should recognize the advancements other disciplines have made in color perception.

Researchers in art and more specifically psychology have contributed considerably to the perceptual effect of hue in color contrast.

Much of the color literature in art and psychology, however, is devoted to the discussion of color appearances involving restricted viewing conditions (i.e., illuminant, temporal and spatial limits). These color appearances such as color constancy (Katz, 1935; Helson, 1943), successive contrast or after-images (Helmholtz, 1924-1925; Birren, 1969a) and simultaneous contrast (Parsons, 1924; Smith, 1965; Chevreul, 1967; Birren, 1969a) are difficult to separate from contrast *per se*. Psychologists Graham and Brown (1965, p. 459) agree with this view: "some experiments bearing on important questions partake more of the nature of studies of color appearances than they do of contrast *qua* contrast."

In view of the difficulty in isolating color contrast from color appearances, a discussion of simultaneous contrast (an instantaneously perceived phenomenon) is in order. The effect of hue on simultaneous contrast is of particular concern in this study, since an understanding of the appearance of hue contrast during rapid recognition of colored map symbols is desirable.

Simultaneous contrast, first founded in theory by the noted color authority M.E. Chevreul (1967) in the 1830's, is instantaneously observed when a colored area is surrounded by a larger region of a different hue.[2] The hue of the smaller area appears altered with the addition of the complementary hue from the surrounding field. The surrounding field also exhibits a hue modification, but in the direction of the complementary hue of the test area. Chevreul compiled a list of hue combinations, with near equal lightness, and indicated the

---

[2] Simultaneous contrast is also observed when either the surrounding or small test area is void of hue. In this case, the effect is called "induction".

hue modifications for each pair of colors in juxtaposition (Table 1). In explanation, example No. 1 shows that green, the complement of red, will change orange to a yellowish hue and blue, the complement of orange, will change red to a violet hue. Complementary color pairs are:

Red, Green
Orange, Blue
Greenish-Yellow, Violet
Indigo, Orange-Yellow

Chevreul did not list hue combinations of exact complements. In the explanatory notes, Birren (Chevreul, 1967, p. 61) pointed out that "... exact complements do not cause hue changes when simultaneously contrasted - they merely heighten the intensity or purity of each other".

Since Chevreul's research on simultaneous contrast, several conditions have been noted as influential variables in the observation of the contrast effect. According to Graham and Brown (1965) these conditions are now considered principles of hue contrast. The conditions are listed as:

1. Relatively small test areas and large surrounding fields create the best simultaneous contrast.
2. Two colors need not be in juxtaposition, but the closer together they are, the greater the contrast effect.
3. When two colors are adjacent, the best color contrast is seen in the region of the border.
4. Simultaneous contrast is maximized when difference in lightness between the test field and surrounding area is absent or minimized.

The last condition is further qualified by psychologists Jameson and

TABLE 1

CHEVREUL'S OBSERVATIONS ON SIMULTANEOUS CONTRAST

	Experimental Hues (equal lightness)	Modifications
1.	Red	inclines to Violet
	Orange	" Yellow
2.	Red	" Violet, or is less Yellow
	Yellow	" Green, or is less Red
3.	Red	" Yellow
	Blue	" Green
4.	Red	" Yellow
	Indigo	" Blue
5.	Red	" Yellow
	Violet	" Indigo
6.	Orange	" Red
	Yellow	" Bright Green, or is less Red
7.	Orange	" Bright Red, or is less Brown
	Green	" Blue
8.	Orange	" Yellow, or is less Brown
	Indigo	" Blue, or is purer
9.	Orange	" Yellow, or is less Brown
	Violet	" Indigo
10.	Yellow	" Bright Orange
	Green	" Blue
11.	Yellow	" Orange
	Blue	" Indigo
12.	Green	" Yellow
	Blue	" Indigo
13.	Green	" Yellow
	Indigo	" Violet
14.	Green	" Yellow
	Violet	" Red
15.	Blue	" Green
	Indigo	" Deep Violet
16.	Blue	" Green
	Violet	" Red
17.	Indigo	" Blue
	Violet	" Red

Source: M.E. Chevreul, 1967, p. 60.

Hurvich (1964) whose work clarifies the function of hue in color contrast. In summary of a previous experiment, Jameson and Hurvich (1964, p. 152) state:

> The frequently cited report that simultaneous color contrast is most prominent when brightness contrast is excluded or is reduced to a minimum does not mean that the operation of the brightness contrast mechanism somehow inhibits or reduces the strength of chromatic interactions. The statement, which is an accurate one, is explained by the fact that the perceived saturation of a color can be reduced by a relative increase in either the whiteness or blackness mode of the achromatic response component. Thus, if a surround field induces in a test area a large amount of blackness, there is a considerable brightness contrast effect. But at the same time the induced blackness desaturates the perceived color in the test area, since the saturation of a color depends on the ratio of chromatic responses to the sum of chromatic plus achromatic responses... Consequently, whenever the magnitude of induced blackness is large relative to the magnitude of induced redness, greenness, blueness or yellowness, the induced hue change forms only a small fraction of the total response change and the observed contast effect will be primarily one of brightness contrast.

In an earlier experiment, Gestalt psychologists Koffka and Harrower (1931) similarly concluded that lightness, rather than hue, is the more influential factor in color contrast. Koffka and Harrower's experimental method differs from Jameson and Hurvich's in that Koffka and Harrower used an "organization" approach to explain the function of hue and lightness in color contrast. Color "organization" is described by Koffka (1935) in terms of the "First Law of Unit Formation and Segregation"; a homogeneously colored field is perceived as a unified part segregated from the environment by the difference in color properties (hue, lightness and chroma).

Koffka and Harrower initially hypothesized that a colored area can always be seen as a unified shape (a result of "organization") on a neutral background having the same lightness. Thus, "organization" of a colored field is not solely dependent on differential lightness. Koffka and Harrower's hypothesis was examined with the following procedure: two equally light gray disks, one with a colored sector and the other with a

gray sector (the gray sector had the same lightness quality as the colored sector), were rotated causing the color and gray sectors to appear as a ring.[3] A lighter gray was added to the gray sector until a ring was produced as clear as the colored sector. For each color (red, yellow, green and blue), a lighter gray in the gray sector was necessary for equal clarity. Koffka and Harrower (1931, p. 163) concluded that hue does contribute to the organizational power of the color, but "mere difference of colour without an accompanying difference in brightness [lightness] has proved to be a very weak organizing force."

In a subsequent experiment carried out by Koffka and Harrower, the gray disks were of equal lightness to the color tested. From the analysis, the researchers qualified their previous statement and added that a hue's contribution to the "organization" of the field results in some loss of chroma. Hues which produce weak "organization" exhibit chroma retention, however, they appear diffused and vacillating. Blue and green, short wavelength hues, have less organizing ability and show more diffusion than red and yellow, long wavelength hues.

Koffka and Harrower followed up their last experiment with a comparison of various color combinations exhibiting a lightness gradient. The structure of their experimental design did not allow testing of color combinations with a constant lightness. (At the time when Koffka and Harrower conducted their research, standardized color materials were not available). Using light, saturated colors, Koffka and Harrower discovered long wavelength hues on short wavelength background to be far superior to short wavelength hues on long wavelength colored backgrounds. Where

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[3] The rotating disk used in Koffka and Harrower's study is called a Maxwell wheel. Description and construction of the Maxwell wheel is explained by Smith (1965).

color combinations exhibited weak "organization", chroma retention was observed.

Hypotheses and Purpose

Research conducted by Koffka and Harrower appears to be the only work in color literature which deals extensively with hue contrast rather than isolated color appearances. However, a limitation of Koffka and Harrower's experiments is that color combinations have not been studied under equal lightness and chroma conditions. The limitation makes their results inapplicable for direct comparison to the present study. Their experiments are, nevertheless, of value in providing a basis for examining perceived difference in hue contrast.

Several hypothesis can be formulated as a logical extension of Koffka and Harrower's research:

1. Various combinations of colored symbols on colored backgrounds without a lightness and chroma gradient exhibit greater contrast ability (differences in hue) than other hue combinations.
2. Certain hue combinations demonstrate better "organization" than other hue combinations.
3. Without differential lightness and chroma between symbol and background, long wavelength hues (e.g., red and yellow) are better organizing colors in the test field than short wavelength hues (e.g., green and blue).
4. Long wavelength hues on backgrounds of short wavelength hues have greater organizing ability than short wavelength hues on backgrounds of long wavelength hues.

These hypotheses are testable in a map like situation, using quantitative analytic methods. Measurement of hue contrast and "organization" can be expressed in quantitative terms (i.e. mean and variance

statistics). The mean is defined for this study as the average numerical response to a display of colored symbols and can be interpreted as a relative measure of hue contrast. Larger mean scores indicate greater chroma retention. Variance, the average deviation from the mean, reflects confusion in numerosity response to ill-defined symbol shapes. The variance statistic is used as an index of symbol "organization" with lower variances indicating greater organizing ability. Justification for these two measures can only be established in theory, thus, the mean and variance statistic must be utilized as operational hypotheses in analyzing contrast differences.

An examination of hue contrast provides a basis of comparison for further study in color contrast. Hue as well as lightness and chroma can never be studied objectively in combination until their separate effects are known. Therefore, the purpose of this research is to measure perceived differences in hue contrast and set up an "organization" ranking of hue combinations. Later this information can be combined with other studies on lightness, chroma, symbol size, and symbol shape to produce a directly usable guide for cartographers selecting contrasting color schemes for thematic maps.

TEST DESIGN

Six hundred (600) subjects were selected from the Geography Department at the University of Alberta to participate in this study. The sample consisted of undergraduate students (527), graduate students (49), faculty (9), and non-academic staff (15). The mean age of those selected was 22 years with a range between 16 and 64 years. Fifty-eight (58) per cent and 42 per cent represented the distribution of males and females, respectively. The subjects were chosen on the criterion of (1) interest and desire to participate in the study, (2) normal visual acuity which was determined by a questionnaire, and (3) normal color vision. The test used in detecting color blindness will be discussed later in this section (see Equipment).

A questionnaire (Appendix A) administered to prospective subjects collected information on age, sex, visual acuity, and experience in the use of color. On the basis of the questionnaire, those prospective subjects who indicated visual difficulties were excluded from the experiment. A review of the collected data revealed that few of the 600 tested subjects with normal color vision and normal visual acuity had previous knowledge of color usage acquired either through professional or formal education experiences. A statistical summary of the 600 subjects sampled is presented in Appendix B.

Selection of Stimulus Materials

Six hues (red, yellow, orange (yellow-red), green, blue and purple) were chosen for experimentation. Intermediate hues (i.e., blue-green and yellow-green) were not considered because a personal survey

of thematic maps found in atlas and sheet form disclosed that the six hues are more commonly used. The additional time necessary for testing more than six hues in every possible combination was also a limiting factor in restricting the number of selected hues.

Colored materials required for simulating the map reading situation necessitated either printing or superimposing (to give the effect of viewing one plane) colored symbols on colored backgrounds. Although colored materials can be matched against color charts, the use of printing inks or artists' "stick-on" colored papers would not provide uniform color quality over the test materials. To insure exact specification of hue, lightness and chroma for easy replication of the experiment, commercially standardized color papers were investigated.

There are many color systems used in industry and scientific research which have been developed for special purposes. Each of these color systems have advantages and disadvantages according to the designated application. Some of the popular color systems are listed in Table 2 with a summary of suitable application and principle defects. While certain popular color systems are based on the principles of additive color mixtures (Ridgway Color System and the Ostwald Color System) or the principles of subtractive color mixtures (Plochere Color System and the Martin-Senour Nu-Hue System), the Munsell Color System is based on the principle of perceived equal steps of color (Wyszecki and Stiles, 1967). The Munsell colored papers were deemed more appropriate in this study, since the materials are standardized for constant hue, lightness, and chroma scales, and within each scale the colored samples are uniformly spaced according to the perception of normal color vision observers. Thus, Munsell standardized color papers were chosen for this study. An international color standard such as the Munsell system facilitates

TABLE 2

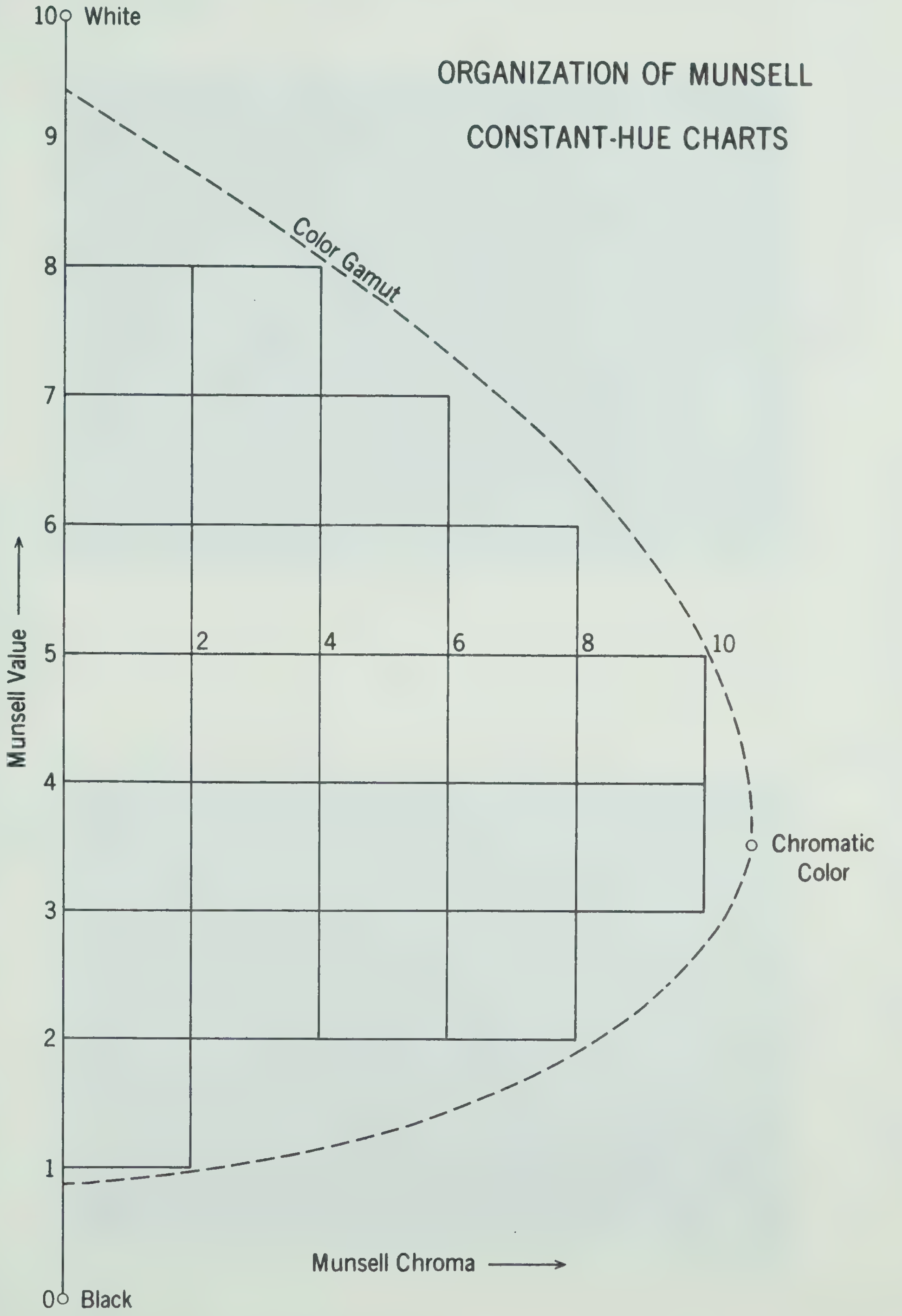
APPLICATION AND PRINCIPAL DEFECTS OF VARIOUS COLOR SYSTEMS

Color System	Principal Use	Secondary Use	Principal Defects
Nu-Hue Custom Color	Sale of prescription-mixed paint	....	Restricted gamut in red-purple to blue hues
Colorizer	Sale of paint	Aid to color matching by customer	System rather complicated
Nu-Hue Color Coordinator	Aid to color matching by painter	Aid to color matching by customer	Nonuniform color spacing
Professional Color Guide	Aid to color matching	....	Too few colors
Plochere	Inexpensive color chips	Aid to color matching	Nonstandardization of paint components
Maerz & Paul	Definition of color names	Color specification	No light, saturated, or near-black colors
Villalobos	Color specification	Selection of harmonious colors	Small size of color chips
Ridgway	Color nomenclature in biology	Color specification in biology	No near-black or near-white colors
Color Harmony Manual	Selection of harmonious colors	Color specification	Ostwald notation not adapted to convenient interpolation or to easy visualization of the color
Munsell	Color specification	Color education	Many of the strongest colors not shown

Source: D.B. Judd, 1952, p. 199.

repeatability of the experiment and satisfies the condition of constant lightness and chroma for testing only hue.

Lightness and chroma levels for the six hues were selected from the library edition of the Munsell Book of Color (1929). The Munsell color atlas is arranged in chart form according to constant-hue, constant-lightness (Munsell uses the term "value"), and constant-chroma. The Munsell constant-hue chart varies in lightness and chroma as shown in Figure 2. Each "box" represents one color. The colored samples, in matte finish, are organized into rows and columns. The rows represent change in chroma. Chroma shifts in perceived equal steps from achromatic colors (black, gray or white) on the left side to saturated colors on the right side of the row. Columns on the hue charts represent change in lightness. The colorants shift, also in perceived equal steps, from very light at the top of the chart to very dark at the bottom. Each hue has a natural limit where the lightness level reaches maximum chroma. According to the Munsell Book of Color this natural limit is called "home value level". Plates 1 and 2 illustrate the "home value level" for the colors, yellow and green, as they appear on their respective constant hue charts. The "home value level" for yellow is Munsell value/8, chroma/12 and for green the level is Munsell value/5, chroma/8. The natural limit varies for different hues. The arrangement of the Munsell constant-value charts is diagramed in Figure 3. Five principle hues (red, yellow, green, blue and purple) and five intermediate hues, combinations of two principle hues, are organized on a 100-point scale around the outer concentric circle. Each hue progresses in ten steps. Radiating lines from the central point (central point indicates a neutral colorant such as black, gray or white) represent constant hue. As the hue progresses from the neutral colorant to the outer circle, chroma increases on an



Source: D. B. Judd, 1952, p. 193.

Figure 2

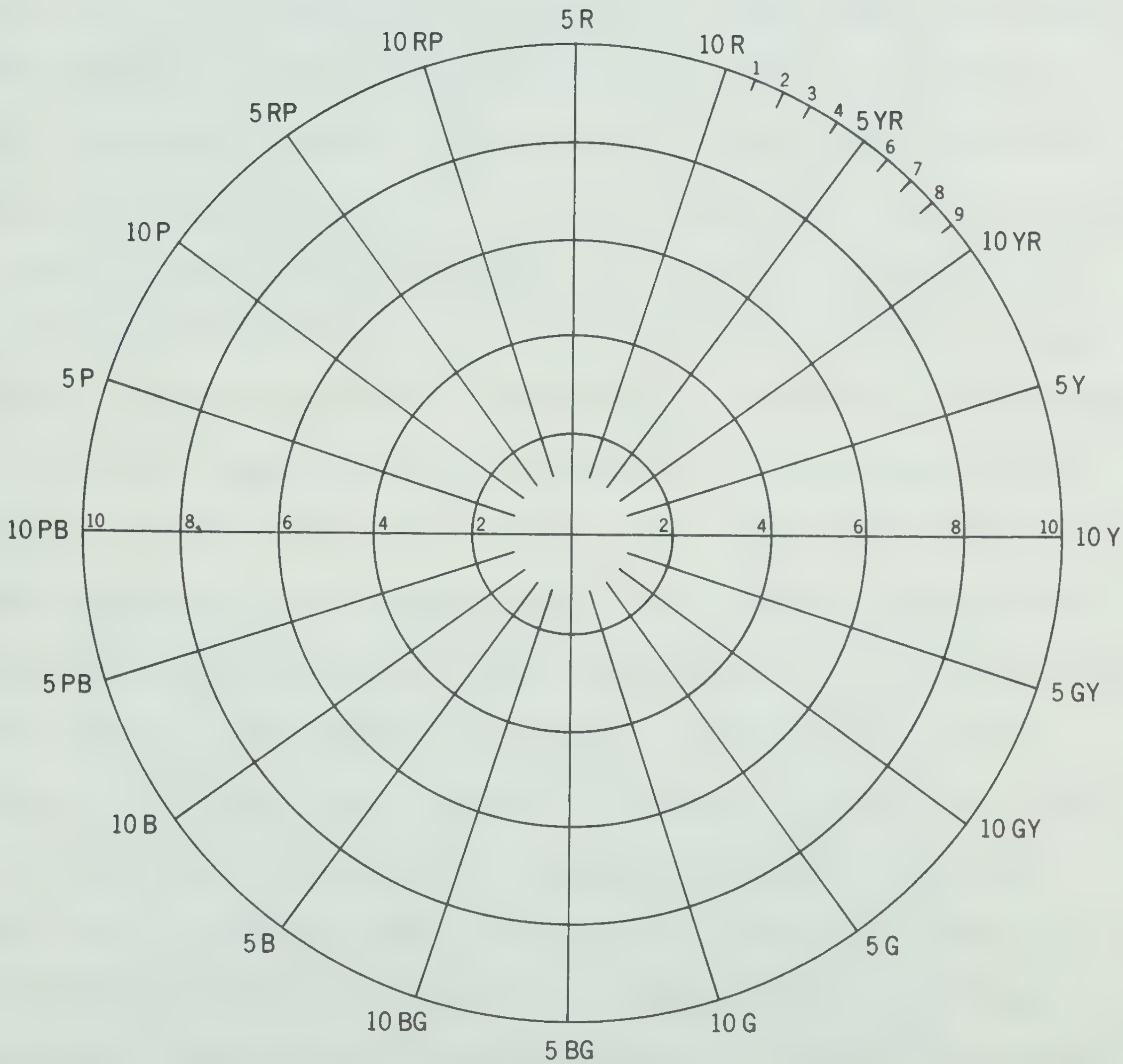
Munsell Constant-Hue Charts
Examples: Yellow and Green

Plate 1

Plate 2

Source: Photocopies from Munsell Book of Color, 1929.

ORGANIZATION OF MUNSELL CONSTANT-VALUE CHARTS



Source: D. B. Judd, 1952, p. 194.

Figure 3

even number scale, 0 to 14; some hues have less than 14 chroma steps. Hues of equal chroma lie on the same concentric circle. Each Munsell constant-chroma chart is arrayed on two pages. Plates 3 and 4 show the arrangement of the five principle and five intermediate hues for Munsell chroma/6. Columns indicate an equal step-wise progression of lightness.

The task of selecting six hues with the same lightness and chroma was simplified by the Munsell constant-hue, -value, and -chroma charts. After studying the charts, the conclusion was made that any choice of equal lightness and equal chroma would not represent the lightest and most saturated hues commonly occuring in nature. The "home value level" for each of the six hues is illustrated in Figure 4. Yellow appears near the top of the Munsell value scale and rapidly changes to a muddy brown as lightness decreases. This change in lightness can be observed on the yellow constant-hue chart in Plate 1. The "home value level" for red, orange, green, blue, and purple occur farther down the lightness scale than yellow's natural limit. An additional complication is that all six hues do not lie on the same chroma level. Since the experiment depended on the selection of six hues with the same lightness and the same chroma, Munsell value/7 and Munsell chroma/6 were chosen as a compromise. Yellow appears slightly muddy, while red, orange, blue, green and purple appear slightly pastel with minimal loss in distinctive saturated characteristic. Samples of the six hues used in this study, along with their Munsell notation and dominant wavelength, are presented in Appendices C and D.

Construction of Stimulus Materials

To construct the target stimuli, two 4.25 x 5 inch cards were cut

Organization of Munsell Constant-Chroma Charts

Example: Constant-Chroma/6

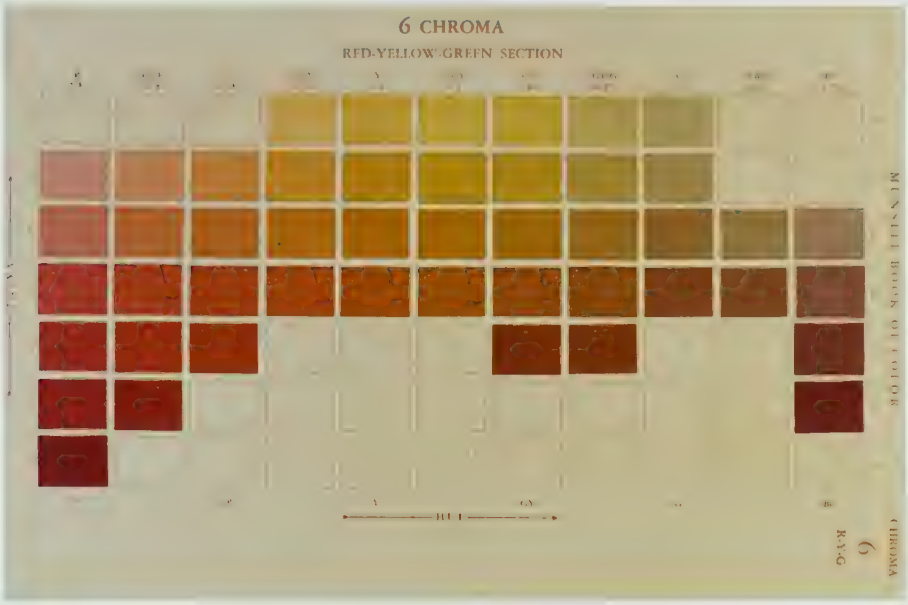


Plate 3

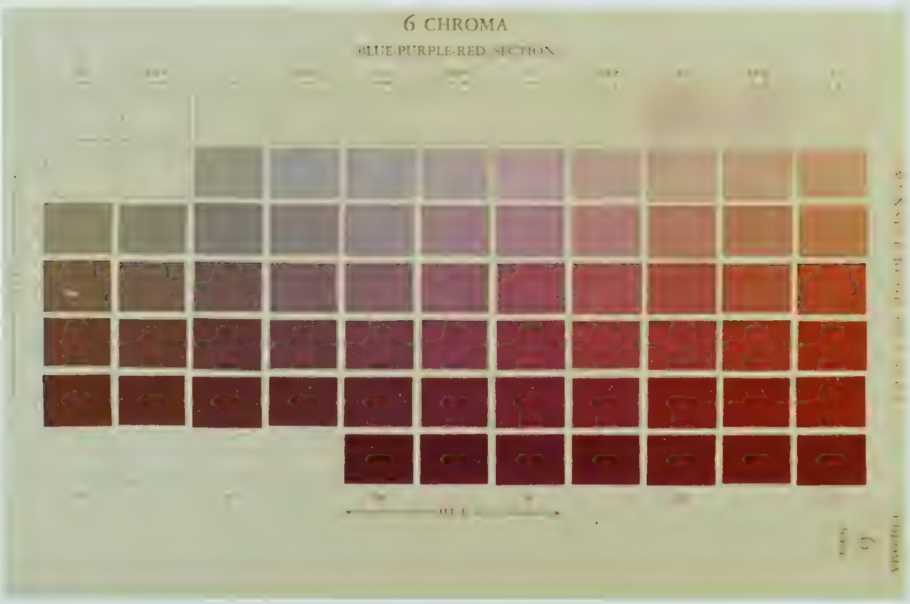
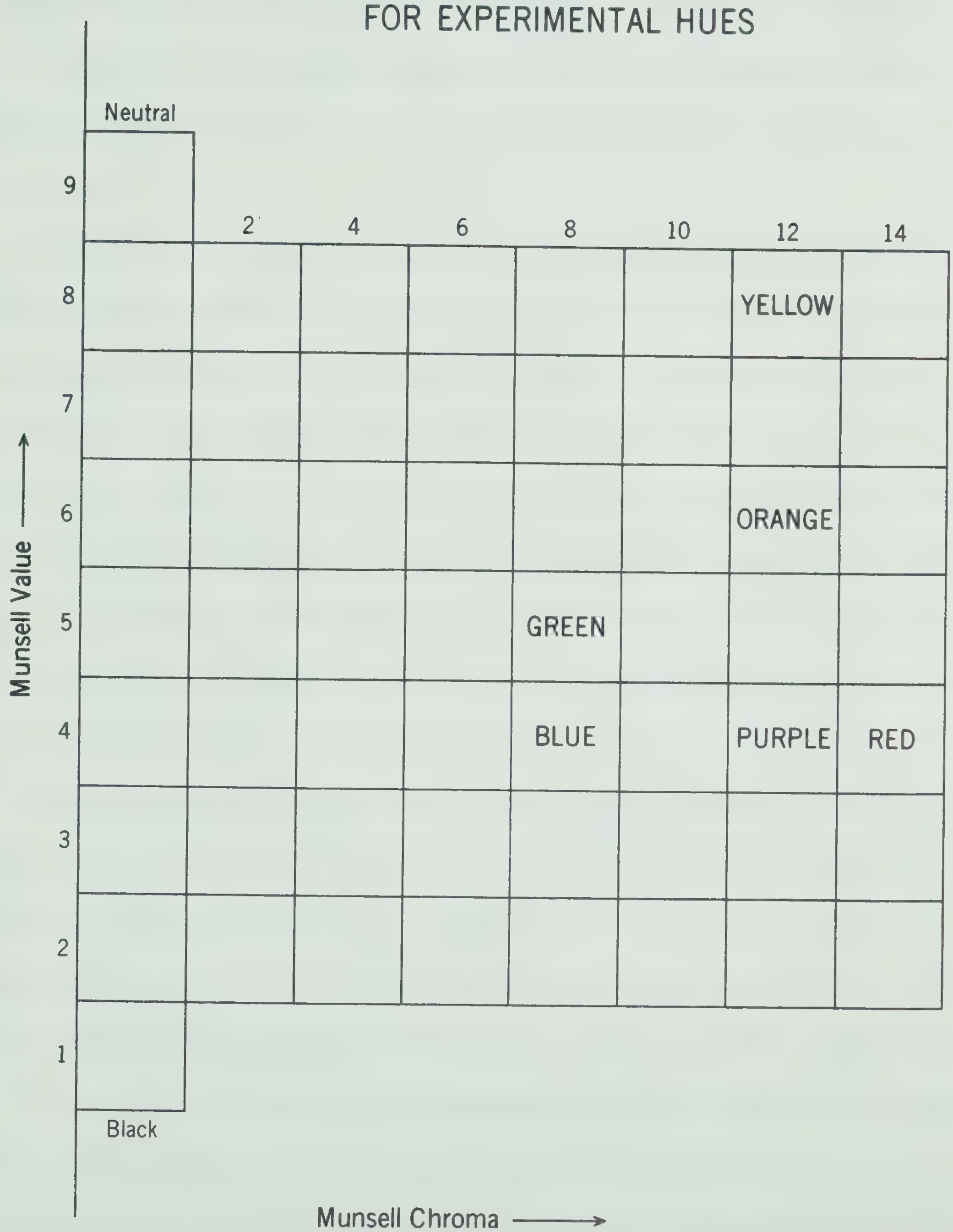


Plate 4

Source: Photocopies from Munsell Book of Color, 1929.

"HOME VALUE LEVEL"
FOR EXPERIMENTAL HUES



Source: Munsell Book of Color, 1929.

Figure 4

from each of the six matte finish Munsell colored papers.[4] One card of each hue was to serve as the symbol stimulus and the other card as the background stimulus. The six hues in all possible background and symbol combination provided 36 visual targets. Inasmuch as combinations of background and symbol cards with the same hue were considered inappropriate for this study, the number of employable targets was reduced to 30.

A number of symbols were punched out of the background cards. The holes allowed another colored card, placed behind the background card, to appear through as the symbol stimulus in the shape of the punched hole. In the final construction of the visual targets, 14 circular holes (dots), .25 inch in diameter and at least .25 inch apart, were cut in the six background cards by an automatic punch. The holes on all six cards were distributed in the same random pattern (Figure 5). As structured arrangements of symbols on thematic maps are rarely found, a random pattern is more analogous to a map situation.

Circles were utilized rather than pictoral mapping symbols, such as trees or crosses, for several reasons. Circles are a common graphic form used in representing data on thematic maps. Secondly, Gestalt psychologists consider the circle a good organizing shape (Koffka, 1935). A study conducted by Hochberg and McAlister (1953, p. 361), concluded that "... the less the amount of information needed to define a given organization as compared to the other alternatives [alternative responses], the more likely that the figure will be so perceived." When perceiving a shape, "goodness" of organization shifts in the direction of minimum change and differences (Koffka, 1935). Thus,

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[4] The dimensions of the cards were restricted by the size of the card-holders on the testing apparatus.

TEST CARD DIMENSIONS

AND RANDOM PATTERN OF DOTS

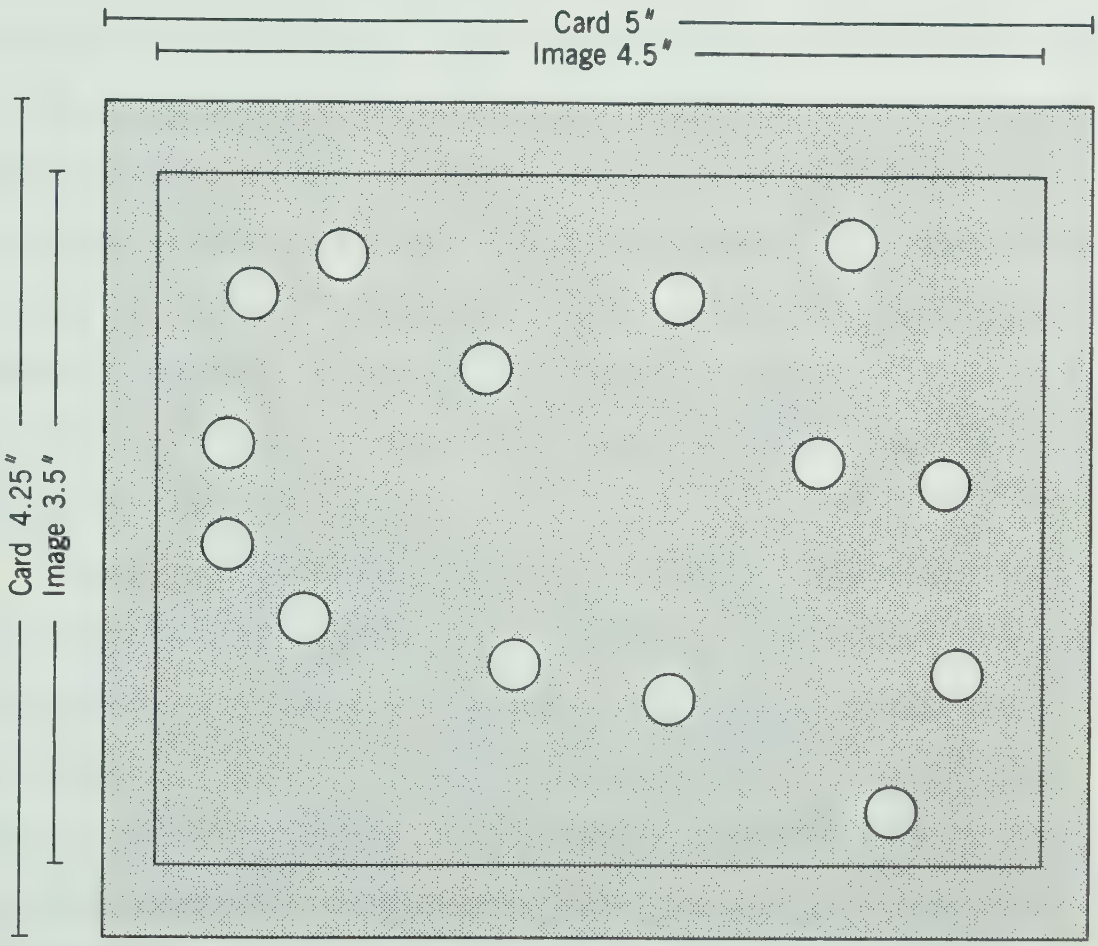

Figure 5

a circle is viewed as more stable and simplistic than a cross, for instance, which can be perceived either as a whole or in several independent parts.

The decision to use 14 dots was made on the basis of psychological findings in number discrimination. There are three response processes involved in number discrimination: subitizing, estimating, and counting (Lechlet, 1971). Subitizing, also called span of attention, is the condition where objects in numbers up to eight can be immediately determined with a high degree of accuracy even though viewing time may be limited. Estimating or numerosity discrimination, as it is often referred to in psychological literature, subsumes the process of guessing a large number of objects under the condition of limited exposure. Estimating, Lechelt (1971, p. 181) writes, "... does not have connotations with respect to accuracy but reflects more of a judgmental than an innate (nativistic) involvement." The last process, counting, employs a numbering system in determining the number of objects. It should be noted that as the array of targets increases in number, the time necessary for counting must be extended.

Numerosity discrimination is of particular importance to this study. While neither subitizing nor counting are appreciably affected by stimulus values, perceptual judgments in estimating can be altered by variations in target characteristics (Lechelt, 1971). With shape and object size held constant and hue the only stimulus variable in this experiment, numerosity discrimination would prove to be a good measure of perceived differences in organizing ability of the 30 hue combinations.

In the course of selecting a number of dots beyond the span of attention, known response biases to certain numbers were considered. Lechelt (1971) reported that a higher percentage of correct responses

was recorded for displays with even numbers than odd numbers. In view of Lechelt's findings and the fact that the 4.25 x 5 inch test cards would not easily accommodate more than 25 dots, the even number 14 was chosen from a set range of 9 to 25 as the numerosity stimuli.

Even though estimates of numerosity are dependent on the exposure period, psychological literature does not provide the researcher with tables of time duration. The large variety of stimulus variables has made compilation of a viewing time table an impossible task. Thus, determining exposure time for this experiment was resolved by pilot studies. Viewing time was reduced until a group of subjects in the pilot study could not count the dots, but still perceived differences in hue. Final exposure time was set at 500 milliseconds. Subjects in the pilot study reported that the rapidity of viewing time eliminated any edge effect resulting from the background card being superimposed on the symbol card.

Equipment

The experiment was conducted in a room illuminated only by fluorescent overhead lights. The room lights were used during testing to maintain eye adaptation to light source output from the equipment.

At one end of the room, A. O. H-R-R Pseudoisochromatic color-blind testing plates were set out on a table. The plates were illuminated by an assimilated daylight New London Easel Lamp suspended over the table. The New London Easel Lamp, designed by Macbeth Corporation (American Optical Co., Catalogue No. 1368), was of sufficient intensity that the room lights did not affect subject response to the Pseudoisochromatic plates.

In the same room, a single unit Model V-0959 tachistoscope (Plate 5) was set up for testing perception of hue contrast. The tachistoscope con-

Equipment Setup

Plate 5

sisted of an exposure cabinet, binocular viewing hood, 0-10 second multi-turn potentiometer time control, two field stops with single-card holders, special hard surfaced chrome sputtered mirror, and a standard 4-watt white fluorescent lamp. The light source output was regulated by a Variac and visually checked on a voltmeter throughout the experiment. The time duration, set by the graduated multi-turn dial, was triggered manually be depressing the operate button on the side panel of the exposure cabinet. The two field stops, one on the back panel and the other on the side panel, allowed for exposure of two sets of cards. The field stop on the side was in continuous view while timer was not in operation. For this study, the side field stop contained a pre-exposure, plain gray card to assist subjects in focusing on the total target area. Upon depressing the timer button, the mirror swiveled to one side to permit full view of the back field stop, which contained in this case a set of background and symbol testing cards.

A 3.5 x 4.5 inch area of each exposure and pre-exposure card was illuminated. The horizontal distance, 4.5 inches, subtended a visual angle of 12.9 degrees at a viewing distance of 20 inches. Each dot provided a visual angle of 44 minutes and 24 seconds. A visual angle of two degrees is generally recognized in psychological literature as the maximum subtending arc to which the eye best receives color stimuli. Therefore, if this study had followed usual psychological visual angle principles, viewing distance would have been approximately ten feet. Considering that thematic maps are generally published in sizes that can be easily handled and read from short distances, ten feet was felt to be an unrealistic viewing distance. However, if strict comparisons were to be made between this work and standard psychophysical research,

"bridge" experiments comparing this visual angle with much smaller ones would have to be conducted.

Procedure

Volunteers for the experiment were told that they would be participating in a study pertaining to perception of color. The questionnaire was administered prior to the experiment period, then each subject having normal visual acuity was escorted to the research room and tested. The first part of the experiment involved screening the subject for defective color vision with the Pseudoisochromatic plates. Only those subjects with normal color vision were used in the perception study.

The normal color vision subject was then seated at the Model V-0959 tachistoscope and the following instructions were given:

> This is an experiment in color perception. The objective of this study is to determine how well people can see colored dots on a colored background. You will be shown a pattern of dots for a brief moment; this pattern is random. You will find that the dots are scattered all over the card rather than forming circles, triangles or crosses like you saw on the color-blind testing cards. Before starting, look straight ahead through the holes in the box and adjust your position on the chair so that you can see the total area of the gray card on the back wall. Keep your eyes focused on the gray card at all times. When you hear the word "ready", I will show you a pattern of dots. The moment you see the dots, tell me how many dots you notice on the card. If you are not sure of the number, make a guess. You will have one practice run and one test. Do you have any questions?

The subject was then presented with the practice card which consisted of a gray symbol paper and a blue background paper punched with two holes, .25 inch in diameter. The blue paper was cut from the same blue material as that used in the actual test. Illumination and viewing time were the same for the trial run and the actual test.

After the practice run, the subject was allowed approximately one minute to rest before preceding with the experiment proper. The

rest period eliminated the problem of an after-image confusing the results in the actual test; after-images are reported to last up to one second (Brown, 1965). Again, the subject was asked to focus on the total area of the gray card. The test with 14 colored dots on a colored background then commenced. Each subject made one observation on one of the 30 colorant stimuli; the color combination was pseudo-randomly selected for the subject. A total of 20 observations were recorded for each of the 30 color combinations.

EXPERIMENTAL RESULTS

Data and Statistical Tests

Visual comparisons of data and non-parametric statistical tests (Kruskal-Wallis one-way analysis of variance by ranks, Spearman's Rank Correlation Coefficient and the one-sample runs test) were used in the analysis of hue contrast and "organization". Although analysis of variance, a more powerful test than the Kruskal-Wallis test, appeared to be an appropriate statistical tool, the data collected in this experiment did not satisfy the normal frequency distribution requirement necessary for the parametric statistical model (Blalock, 1960). Figure 6a and 6b show the frequency distribution of numerosity response to color combinations red on blue and orange on red. The two hue combinations, used as examples of the other 28 combinations, are skewed in a positive direction. Moreover, some of the color combinations exhibit a bimodal pattern. For these reasons, distribution-free tests were employed in the analysis of data.

From the raw scores collected in the numerosity discrimination test, the mean and variance were calculated for each of the 30 hue combinations. Raw scores as well as means and variances are recorded in Appendix E.

Hypothesis I

The Kruskal-Wallis one-way analysis of variance by ranks test was used to determine whether statistically significant differences in contrast exist between hue combinations measured by numerosity response.[5]

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[5]The chi square test would be inefficient in this analysis since the small sample size of 20 observations would leave more than 20 per cent of the cells with an expected frequency of less than five (Siegel,1956, p. 178).

FREQUENCY DISTRIBUTION OF NUMEROSITY RESPONSE

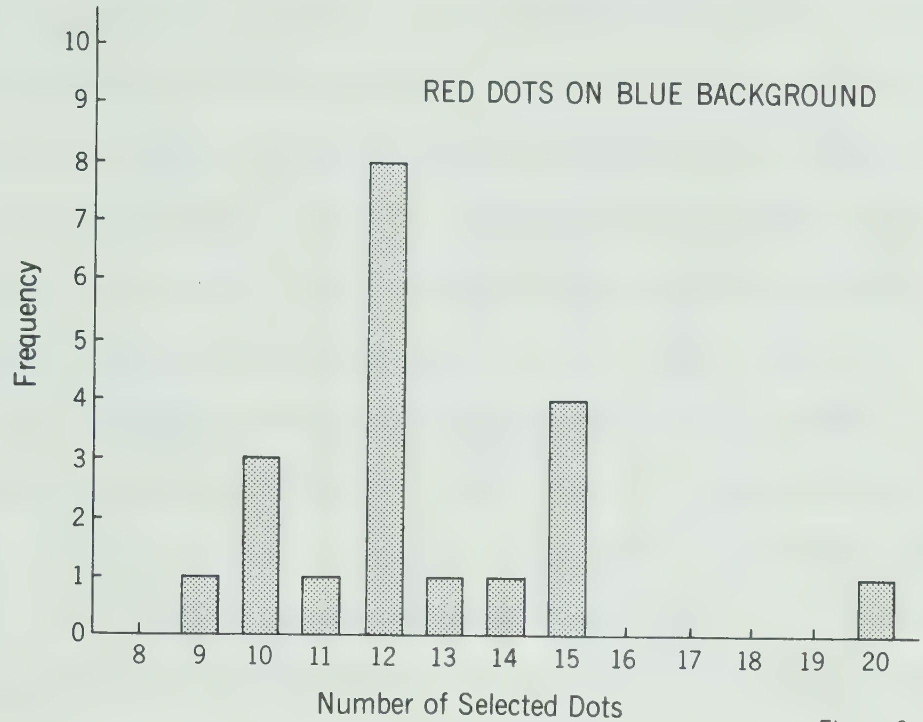


Figure 6a

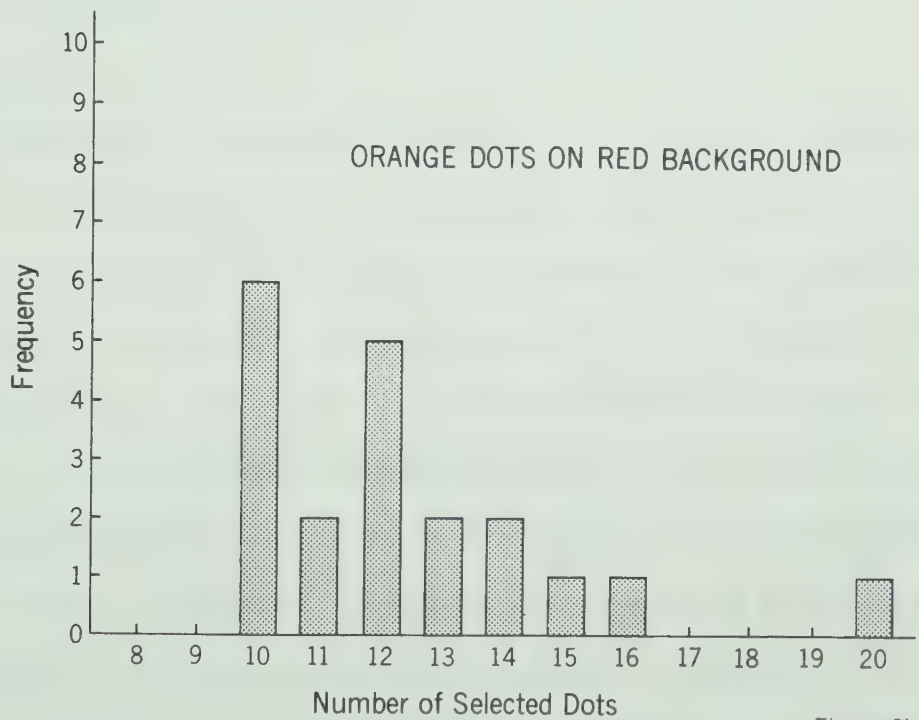


Figure 6b

Source: Experimental Data.

Four hundred thirty-five (435) separate tests were undertaken comparing every possible permutation of symbol and background hue combination. Results are summarized in Table 3. The top right portion of Table 3 is grouped according to symbol hue and the bottom left portion, while replicating the data in the top half, is grouped according to background hue. The numbers indicate statistical results of significantly different hue combinations. Level of significance is coded at the side of the number. For example, hue combinations green on orange (GO) and green on blue (GB) are significant at the one per cent level.

It is apparent from Table 3 that relative to the number of comparisons made, few permutations are statistically significant at a predetermined minimum level of 5 per cent. The short range between means (11.05 to 14.05) hinders the detection of fine disparities which may exist among the 30 hue combinations. However, one can conclude that differences in hue contrast were observed by the subjects under the existing experimental conditions.

Hypothesis II

According to Koffka and Harrower's (1931) theory, superior "organization" of the test field is accompanied by a loss in chroma purity. To quantify their theory, it is convenient to define chroma retention as the "correctness" of mean score and "organization" as the average deviation from the mean score (or variance). Direct relationships between these statistics and the phenomena observed by Koffka and Harrower cannot be conclusively determined, but must be presented as untestable hypotheses.

If these operational hypotheses can be assumed as valid, it is then correct to state the relationship between the mean and variance (Figure 7). In Figure 7, hue combinations are ordered from the lowest mean score at top of the graph to the highest mean score at the bottom. All

TABLE 3

SIGNIFICANTLY DIFFERENT HUE COMBINATIONS

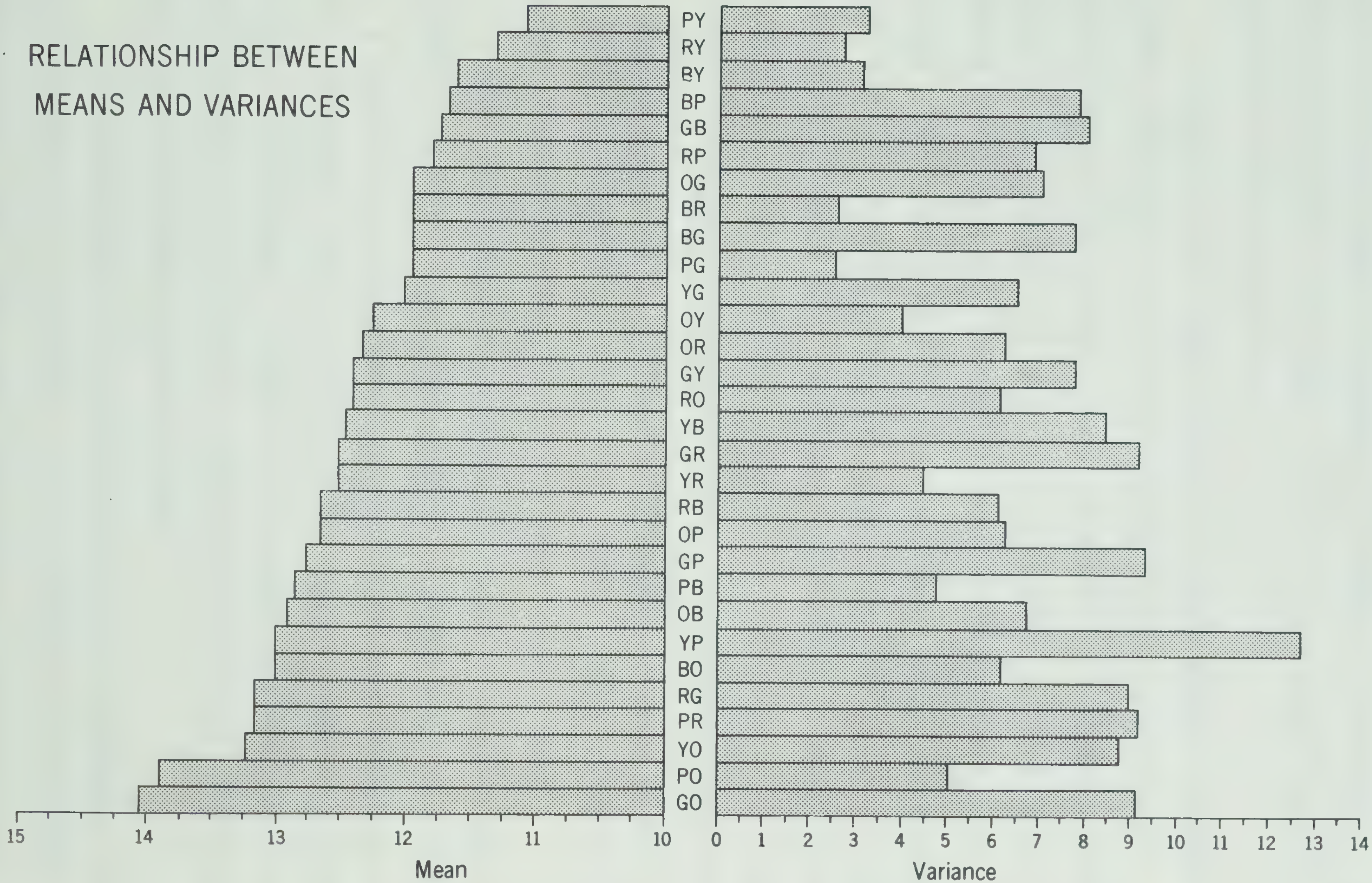
	BG	BY	BO	BR	BP	GB	GY	GO	GR	GP	YB	YG	YO	YR	YP	OB	OG	OY	OR	OP	RB	RG	RY	RO	RP	PB	PG	PY	PO	PR	
		--	--	--	--	--	--	5.48°	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.69*	--	BG
RP			--	--	--	--	--	7.11*	--	--	--	--	--	--	--	--	--	--	--			--	--	--	--	--	--	--	--	--	BY
OP	--			--	--	4.19°	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.30°	--	--	--	--	7.48*	--	--	BO
YP	--	--			--	--	--	5.43°	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.84	--	BR
GP	--	--	--			--	--	7.05*	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.68*	--	--	BP
BP	--	--	--	--			--	7.50*	--	--	--	--	3.99°	--	--	--	--	--	--	--	--	--	--	--	--	4.26°	--	--	10.77*	--	GB
PR	--	--	--	--	--			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	GY
OR	--	--	--	--	--	--			--	--	3.87°	5.28°	--	--	--	--	5.84°	--	--	--	--	--	9.42*	--	6.67*	--	5.27°	11.17*	--	--	GO
YR	--	--	--	--	--	--	--			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	GR
GR	--	--	--	--	--	--	--	--			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	4.33°	4.11°	--	GP
BR	--	--	--	--	--	--	--	--	--			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.33°	--	YB
PO	8.77*	--	--	4.11°	--	--	5.34°	--	--	7.84*			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	8.42*	--	YG
RO	--	--	--	--	--	--	--	--	--	--	5.21°			--	--	--	--	--	--	--	--	--	5.02°	--	--	--	--	7.12*	--	--	YO
YO	--	--	--	--	--	--	--	--	--	--	--	--			--	--	--	--	--	--	--	--	--	--	--	--	--	5.09°	--	--	YR
GO	6.67*	--	--	--	7.05*	--	--	--	--	5.43°	--	--	--			--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	YP
BO	--	--	--	--	--	--	--	--	--	--	--	--	--	--			--	--	--	--	--	--	3.97°	--	--	--	--	5.94°	--	--	OB
PY	--	5.16°	--	4.33°	8.69*	6.39°	--	5.09°	--	--	14.26*	3.97°	7.12*	11.17*	7.48*			--	--	--	--	--	--	--	--	--	--	--	8.00*	--	OG
RY	--	--	--	--	--	4.37°	--	--	--	--	12.80*	--	5.02°	9.42*	5.30°	--			--	--	--	--	--	--	--	--	--	--	4.13°	--	OY
OY	--	--	--	--	--	--	--	--	--	--	4.13°	--	--	--	--	--	--			--	--	--	--	--	--	--	--	--	5.34°	--	OR
GY	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--			--	--	--	--	--	--	--	5.16°	--	--	OP
BY	--	--	--	--	--	--	--	--	--	--	--	--	--	7.11*	--	--	--	--	--			--	--	--	--	--	--	5.22°	--	--	RB
PG	--	--	--	--	--	--	--	--	--	--	8.22*	--	--	5.27°	--	--	--	--	--	--			4.51°	--	--	--	--	6.40°	--	--	RG
RG	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.40°	4.51°	--	--	--	--			--	--	5.57°	--	--	12.80*	4.37°	RY
OG	--	--	--	--	--	--	--	--	--	--	8.00*	--	--	5.84°	--	--	--	--	--	--	--	--			--	--	--	3.97°	5.21°	--	RO
YG	--	--	--	--	--	--	--	--	--	--	8.42*	--	--	5.28°	--	--	--	--	--	--	--	--	--			--	--	--	8.77*	--	RP
BG	--	--	--	--	--	--	--	--	--	--	6.69*	--	--	5.48°	--	--	--	--	--	--	--	--	--	--			--	7.05*	--	--	PB
PB	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.05*	5.57°	--	--	--	--	--	--	--	--			--	8.22*	--	PG
RB	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.22°	--	--	--	--	--	--	--	--	--	--			14.26*	6.39°	PY
OB	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	5.94°	3.97°	--	--	--	--	--	--	--	--	--	--			--	PO
YB	--	--	--	--	--	--	--	--	--	--	6.33°	--	--	3.87°	--	--	--	--	--	--	--	--	--	--	--	--	--	--			PR
GB	--	--	--	--	--	--	--	--	--	--	10.77*	--	3.99°	7.50*	4.19°	--	--	--	--	--	--	--	--	--	--	--	--	--	--		
	RP	OP	YP	GP	BP	PR	OR	YR	GR	BR	PO	RO	YO	GO	BO	PY	RY	OY	GY	BY	PG	RG	OG	YG	BG	PB	RB	OB	YB	GB	

Source: Experimental Data.
Statistical Significance Level: Siegel, 1956, p. 249.

°P < .05
*P < .01

Note: The table at the top right is organized according to symbol hue and the table at the bottom left is organized according to background hue. Groups outlined have identical symbol or background hue.

RELATIONSHIP BETWEEN MEANS AND VARIANCES



Source: Experimental Data.

Figure 7

the scores except for one are smaller than 14. This one exception, however, does not disrupt the ranking of "correctness" magnitude. Recorded at the right of the mean scores is the corresponding variance statistic for each hue combination.

A cursory view of Figure 7 does not clearly disclose confirmation of Koffka and Harrower's theory, since a positive trend (distinct) pyramid effect) is not obvious. Variances appear to be randomly distributed along the y-axis of the graph in no particular relation to the direction of ranked means. However, a closer study reveals a slight narrowing of the graph near the top, indicating a possible correlation between mean and variance statistics. Results from the Spearman's Rank Correlation Coefficient test prove the relation between means and variances to be reliably associated and positive (Rho = +0.46, $t = 2.74$, d.f. 28, $p < 0.01$). Therefore, the experimental data is in agreement with Koffka and Harrower's thesis and by inference "correctness" of mean score indicates chroma retention and variance is a likely measure of hue "organization". The lower variance indicates greater "organization".

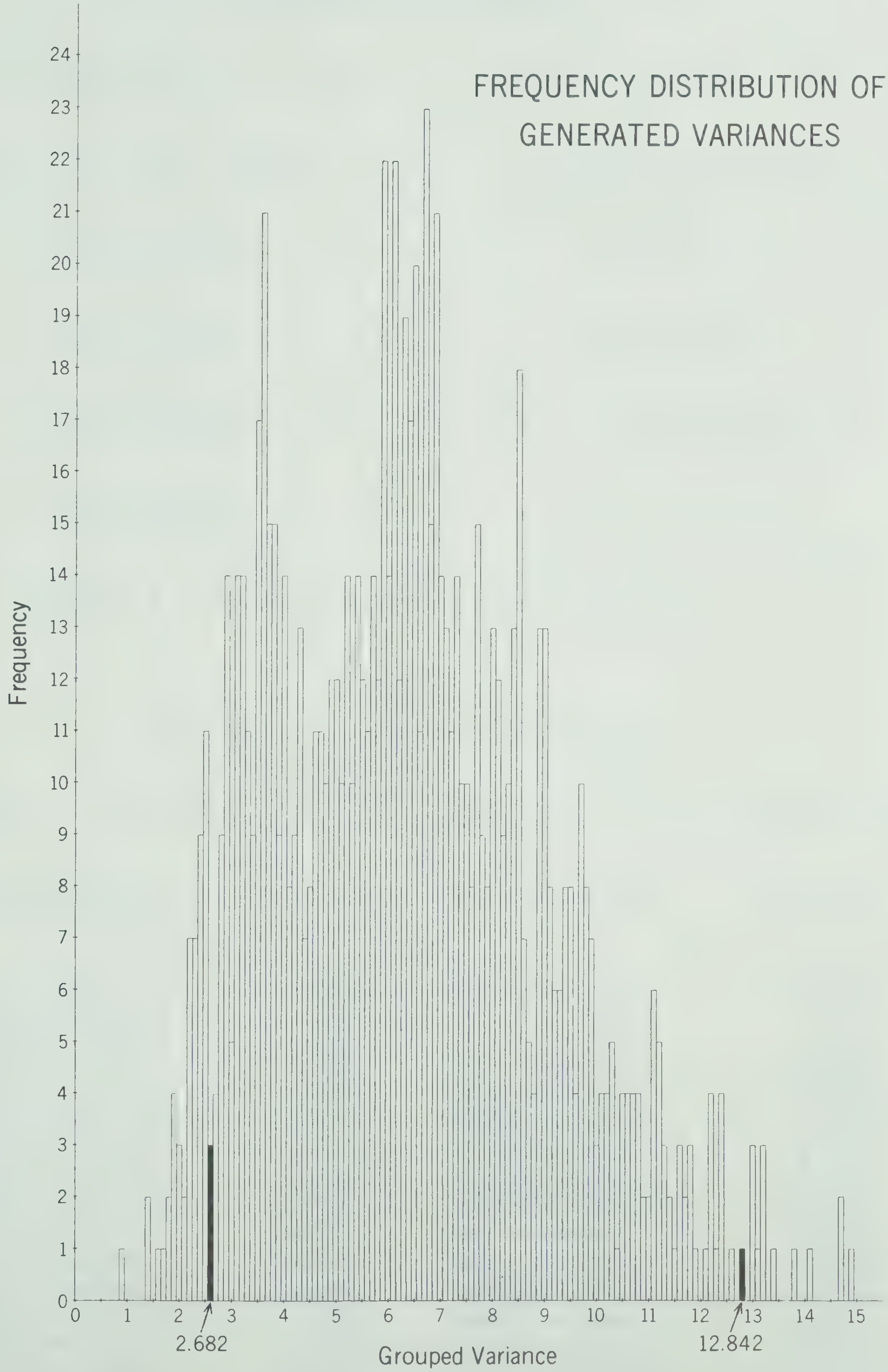
Before making further conclusions as to the validity of variances, the probability that the variances occurred by chance had to be considered. While a non-parametric statistical test has not yet been devised to establish differences between variances (West, 1972), a probability model was set up using the data collected in the numerosity discrimination study. The probability model only explains whether the highest and lowest variances in this experiment occurred by chance.

A frequency distribution (uniform as opposed to exponential or normal) of variances was generated, from the 600 total original data, by randomly drawing (with replacement) 1000 samples of 20 observations.

Variance was calculated for each of the 1000 samples and plotted as a histogram (Figure 8) in class intervals of 0.0999 (i.e., 0-0.0999, 0.1000-0.1999 ... 14.9000-14.9999). Study of Figure 8 indicates that out of 1000 samples, 13 generated variances are greater than the highest experimental variance (12.842) and 50 generated variances are less than the lowest experimental variance (2.682). This means that a variance of 2.682 has a probable chance of occurring randomly 5 per cent of the time and a variance of 12.842 only 1.3 per cent of the time. Thus, the lowest and highest variances in the present study are non-randomly drawn from the 30 groups at a significance level of 20 and 13 per cent, respectively. Conclusions cannot be made from Figure 8 about the probabilistic nature of the other variances calculated in the experiment proper, however, the possibility of significant differences among these variances cannot be discounted. It is also probably correct to infer that at least the highest and lowest variances are significantly different from each other, although this does not necessarily follow from the analysis.

Hypotheses III and IV

Koffka and Harrower's list of organizationally superior hue combinations (Table 4) and the ranking of calculated variances in this study (Table 5), show many similarities. The first three superior hue combinations in Table 4 have lower variances (better "organization") in Table 5 than the corresponding color combination to which Koffka and Harrower compared the superior combination. The last superior color combination (yellow on blue) in Table 4 shows a slightly higher variance in Table 5 than the compared color combination (green on blue). In view of the close proximity of yellow on blue and green on blue in the variance ranking and the small difference in variance scores, there may not be a significant difference in organizational ability between the two hue com-



FREQUENCY DISTRIBUTION OF GENERATED VARIANCES
Frequency
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
2.682
12.842
Grouped Variance

Figure 8

TABLE 4

SUMMARY OF KOFFKA AND HARROWER'S COLOR COMBINATION EXPERIMENTS

Color Combinations Compared	Superior Combination
yellow on blue yellow on red	yellow on red
blue on yellow red on yellow	red on yellow
blue on yellow green on yellow	blue on yellow
yellow on blue green on blue	yellow on blue

Source: K. Koffka and M.R. Harrower, 1931, p. 181.

TABLE 5

RANKING OF HUE COMBINATIONS BY VARIANCE

Hue Combination	Variance	Hue Combination	Variance
Blue on Red	2.682	Orange on Blue	6.766
Purple on Green	2.682	Red on Purple	7.011
RED ON YELLOW	2.853	Orange on Green	7.103
BLUE ON YELLOW	3.200	Blue on Green	7.839
Purple on Yellow	3.313	Blue on Purple	7.924
Orange on Yellow	4.092	GREEN ON YELLOW	7.937
YELLOW ON RED	4.579	GREEN ON BLUE	8.221
Purple on Blue	4.800	YELLOW ON BLUE	8.576
Purple on Orange	5.187	Yellow on Orange	8.880
Red on Blue	6.239	Red on Green	9.082
Blue on Orange	6.316	Green on Orange	9.208
Red on Orange	6.358	Green on Red	9.316
Orange on Red	6.450	Purple on Red	9.397
Orange on Purple	6.450	Green on Purple	9.461
Yellow on Green	6.632	Yellow on Purple	12.842

Source: Experimental data.

binations. With the variance ranking of the six hue combinations closely approximating Koffka and Harrower's results, additional support is given the operational hypothesis that variance is a valid measure of "organization".

In a more stringent analysis of Koffka and Harrower's theory, a one-sample runs test was used to compare the data from the present study with the theory of organizational superiority of test fields containing long wavelength hues, (i.e. red, yellow, orange and purple.)[6] It is important to note that the hue combinations employed in Koffka and Harrower's experiments had differential lightness while the hue combinations in this study did not. In accordance with Koffka and Harrower's theory, the expected ranking of long wavelength test fields (L) and short wavelength test fields (S) would be as follows:

L L L L L L L L L L L L L L L L L L L L S S S S S S S S S S

If the rank ordering of hue combinations according to variance agrees with the sequence suggested by Koffka and Harrower, the conclusion can be made that regardless of lightness differences long wavelength hues in the test field contribute more to the "organization" of the symbol than short wavelength hues.

The one-sample runs test was set up by ranking the 30 test hue combinations in increasing magnitude of variance. The series of long wavelength (L) and short wavelength (S) test fields occur in this order:

$$\underset{1}{\underline{S}}\ \underset{2}{\underline{L\,L}}\ \underset{3}{\underline{S}}\ \underset{4}{\underline{L\,L\,L\,L\,L\,L}}\ \underset{5}{\underline{S}}\ \underset{6}{\underline{L\,L\,L\,L\,L\,L\,L}}\ \underset{7}{\underline{S\,S\,S\,S}}\ \underset{8}{\underline{L\,L\,L}}\ \underset{9}{\underline{S\,S}}\ \underset{10}{\underline{L}}\ \underset{11}{\underline{S}}\ \underset{12}{\underline{L}}$$

---

[6] It may seem unusual to classify purple as a long wavelength hue. Purple hue has a characteristic wavelength of about 400 millimicrons which is shorter than the wavelength for blue and green. The wavelength of the desaturated purple used in this study is longer than blue and green, and closer in length to yellow (See Appendix D).

Total number of runs (defined as the number of successions of identical symbols which are preceded and followed by different symbols or by no symbols at all) in this array is 12. At a significance level of 5 per cent, the "r" value (12) falls between critical values of 10 and 22 (Siegel, 1956, pp. 252-253) which indicates that the sample is not significantly different from random series of L's and S's.

Since Koffka and Harrower only used red, yellow, green and blue hues in their experiment, purple and orange may have influenced the ranking of long and short wavelength test fields. Red, yellow, green and blue appear as distinctly different hues while purple and orange appear as two-color mixtures (Hochberg, 1964). Purple is a combination of red and blue, and orange a combination of red and yellow. If during the experiment response to purple or orange was altered by visual fluctuations between the colors' corresponding hue mixture, purple and orange might have disrupted the ranking of variances.

Therefore, with purple and orange eliminated from the ordered sequences of variances, the one-sample runs test is again applied to the data. Succession of long and short wavelength test fields occurs in the following order:

$$\underset{1}{\underline{S}}\quad \underset{2}{\underline{L}}\quad \underset{3}{\underline{S}}\quad \underset{4}{\underline{L\ L\ L}}\quad \underset{5}{\underline{S\ S\ S}}\quad \underset{6}{\underline{L\ L}}\quad \underset{7}{\underline{S}}$$

This sequence of L's and S's also proves random ($r = 7$, $p > 0.05$). By inference, purple and orange did not disrupt the ranking of long and short wavelength test fields in the previous runs test.

Symbols of long wavelength hues have proven neither superior nor inferior to symbols of short wavelength hues; symbol and background hue combinations of long wavelength on long wavelength were not singled out from long wavelength on short wavelength, and neither were combinations

of short wavelength on long wavelength singled out from short wavelength on short wavelength. Koffka and Harrower theorized that long wavelength hues on short wavelength colored backgrounds would express greater organizing ability than the converse wavelength situation. Thus, the expected sequence of long on short wavelengths (ls) and short on long wavelengths (Sl) would appear as:

Ls Ls Ls Ls Ls Ls Ls Ls Sl Sl Sl Sl Sl Sl Sl Sl

With the experimental data ranked from lowest to highest variance, the mixture of Ls's and Sl's occurs as follows:

Sl	Ls	Sl	Ls Ls	Sl	Ls Ls Ls	Sl Sl	Ls Ls	Sl Sl Sl
1	2	3	4	5	6	7	8	9

The number of runs (9) falls between the critical values of 4 and 14. At a significance level of 5 per cent, long on short wavelength hues are not superior or inferior to short on long wavelength hues; the Ls's and Sl's are randomly distributed over the range of variances.

Aside from Koffka and Harrower's suggested wavelength superiority rankings, five other symbol and background combinations of long and short wavelength hues as well as background wavelength combinations alone were tested for greater organizing ability. Summarized in Table 6 are the results from the one-sample runs tests. In every case the wavelength combinations are randomly ranked.

TABLE 6

SUMMARY OF ONE-SAMPLE RUNS TEST FOR RANDOMIZATION OF HUE WAVELENGTH COMBINATIONS

Hue Wavelength Combinations	"r" Value	Critical Values at 5% Significance Level*	Conclusion
Long on Long vs Long on Short	12	6-16	Random
Long on Long vs Short on Long	12	6-16	Random
Long on Long vs Short on Short	--	----	Random (by observation)
Long on Short vs Short on Short	--	----	Random (by observation)
Short on Long vs Short on Short	--	----	Random (by observation)
Long background vs Short background	17	9-20	Random

* Critical values taken from Siegel, 1954, pp. 252-253.

SUMMARY AND CONCLUSIONS

This study, while technical in nature, employed a perceptual approach to investigating hue contrast with specific application to thematic maps. Until recently, cartographers have not engaged in studies of visual impact of graphics on the map reader. Even with the increased interest in cartographic psychophysics, the perceptual study of color in mapping has progressed little beyond the theoretical stage. For this reason, the primary source of literature in the present study has been drawn from psychology, with limited amounts from cartography.

In the review of literature on color contrast, it was noted that psychologists (Koffka and Harrower, 1931; Jameson and Hurvich, 1964) as well as cartographers (Keates, 1962; Robinson, 1967; and Wood, 1968) were consistent in their opinion that hue difference alone was not an effective component of color contrast. While the view held by cartographers was based primarily on experiments conducted by researchers in other disciplines, psychologists have substantiated their conclusion with empirical studies. A psychological experiment was carried out by Koffka and Harrower (1931) in which brightness difference was compared with hue difference. The experiment involved judging which of two gray disks, the disk with an equally light colored sector or the gray disk with a differentially light gray sector, produced the sharpest ring. Under these con-

ditions, the researchers concluded that although hue appeared as a visible ring, hue exhibited poor organizational ability. Koffka and Harrower did not extend their study to the effects of colored sectors on colored disks of equal lightness. However, in a subsequent series of experiments colored sectors on colored disks with lightness gradients were compared. They found that hue combined with a lightness difference revealed a distinct ring and some hue combinations exhibited greater clarity than others. Difference in clarity was explained by wavelength; long wavelength hues on short wavelength backgrounds were found superior to short wavelength hues on long wavelength backgrounds. With lightness a variable in their experiment, it is impossible to distinguish hue from lightness effects. Consequently, Koffka and Harrower's experiments posed several questions: (1) do combinations of colored symbols on colored backgrounds without a lightness gradient contribute anything to color contrast, (2) do certain hue combinations exhibit greater organization, (3) are long wavelength hues better organizing colors in the test field than short wavelength hues, and more specifically, (4) do long wavelength colored test fields on short wavelength colored backgrounds <u>without</u> a lightness gradient demonstrate the same organizational superiority as <u>with</u> a lightness gradient?

The method employed in the present study was designed to eliminate variability in lightness and chroma, and in addition, to provide a more quantitative and controlled experiment than Koffka and Harrower's. While quality controlled color materials were not available when Koffka and Harrower conducted their experiments, the standardized colored papers used in this study facilitated exact regulations and experimental

replication of hue, lightness and chroma stimuli.

The experiment involved asking normal color vision subjects to estimate the number of colored dots on a colored background. Hue was the only variable; the same lightness and chroma levels were used for all symbol and background colors. Each stimulus card exhibited 14 dots that were distributed in an identical random pattern. Colorant stimuli were displayed in a viewing box (tachistoscope) at a distance simulating a normal map reading situation. Testing was conducted under conditions of constant illumination and a limited exposure time (500 milliseconds) which precluded counting.

Analysis of numerosity responses revealed that subjects perceived few measurable differences in contrast among the 30 hue combinations. The results concur with the findings of previous researchers Koffka and Harrower (1931), Jameson and Hurvich (1964): hue is _not_ an important factor in producing differences in color contrast. These results more specifically indicate that _few_ combinations of colored symbols on colored backgrounds without a lightness and chroma gradient create effective differential contrast.

Only one occurrence of a background hue showing consistent influence on contrast ability was found (Table 3). Various hue combinations of purple symbols on other colored backgrounds proved significantly different in contrast; however, this one observation furnishes insufficient evidence to conclude that background hue is the controlling agent in hue contrast. Table 3 also shows that symbol hues do not exhibit a consistent influence on contrast effects. It appears that contrast differences can not be explained solely by the contribution of either background or symbol hue. The answer to contrast ability must exist exclusively in the _interaction_ between back-

ground and symbol hue. Thus, a closer examination of simultaneous contrast is warranted.

While one hue combination may be perceived as superior in contrast effect (measured by a mean score closer to 14) another hue combination with a lower variance score will exhibit greater "organization" of the symbol. In this study, comparisons of symbol "organization" were not measured by the same visual tests that Koffka and Harrower utilized, but through the indirect method of analyzing variance scores (variance being the average amount of deviation from the mean). Therefore, an operational hypothesis was set up based on the rationale that confusion in numerosity response to ill-defined shapes would be reflected in deviation from the mean. The operational hypothesis was stated as:

> The variance statistic is an index of symbol "organization," with lower variances indicating greater organizing ability.

There was no substantiating proof of the relation between shape enhancement and the variance statistic. However, convincing evidence of a relationship was provided by Koffka and Harrower (1931). They theorized that a hue's contribution to "organization" of a test field results in a loss of chroma. In the present experiment, an examination of Koffka and Harrower's theory entailed comparing mean scores with variances. The mean score was interpreted as a relative measure of hue contrast and further defined as an indicator of chroma retention (i.e. greater chroma retention is likely to influence the "correctness" of perceived number of dots). The latter definition, while logical in theory, could not be conclusively established by the present experimental design. If a ranking of means denoting relative range

of chroma retention can be assumed as valid, then examining the correlation between means and variance was justified. A subsequent comparison of mean and variance rankings showed <u>decreasing</u> magnitude of means to be statistically significant (5% level) with <u>increasing</u> magnitude of variances. Interpreted in terms of chroma retention and organizational power, it can be concluded that hue's contribution to the "organization" of a symbol is generally accompanied by a loss of chroma.

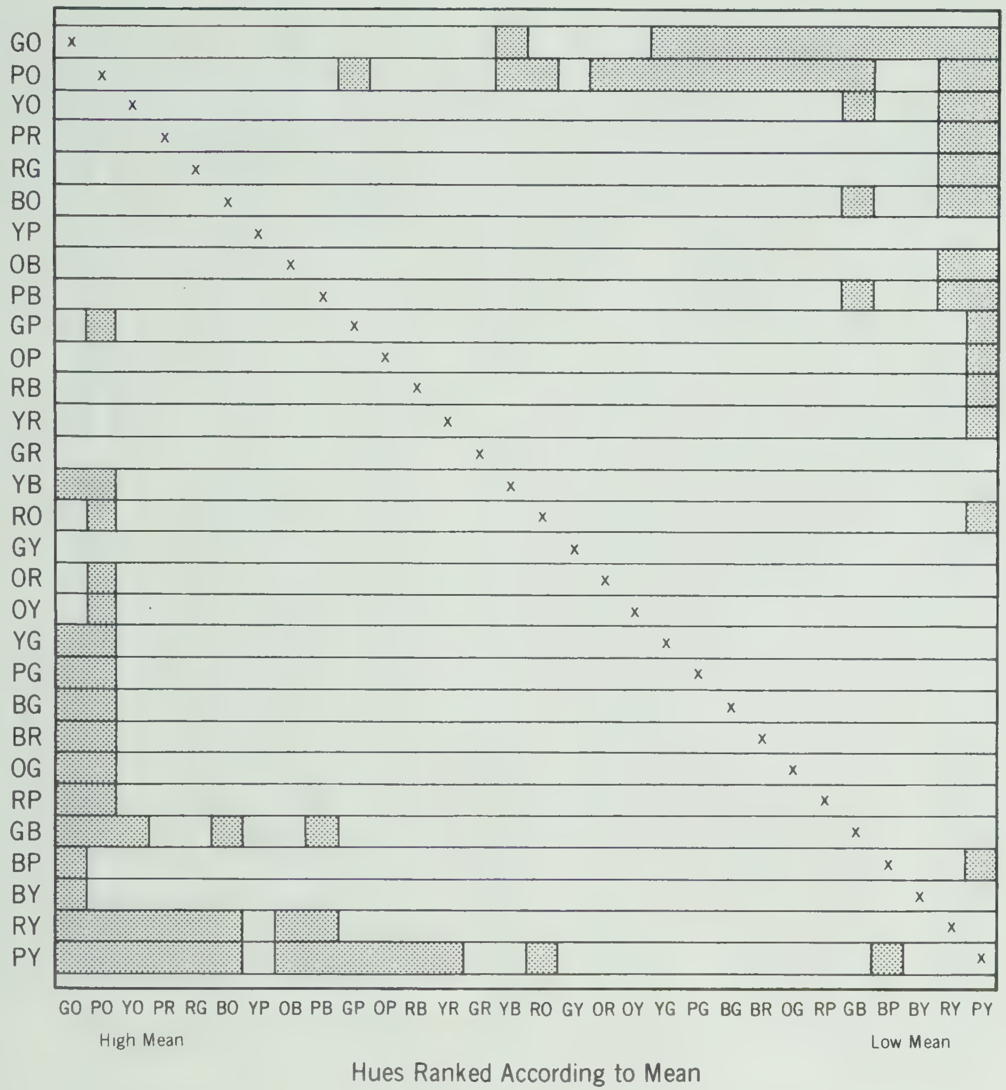
Strong "organization" of certain hue combinations was found unexplainable by the proposed long and short wavelength theory. While the ordering of variances closely matched Koffka and Harrower's listing of superior color combinations, neither test fields of long wavelength hues nor the more categorically defined test fields of long wavelength hues on short wavelength backgrounds demonstrated an overall trend of organizational superiority. All possible arrangements of ranked long and short wavelength hues in test field and background were examined. However, no one combination of ranked long and short wavelengths proved stronger in organizing ability.

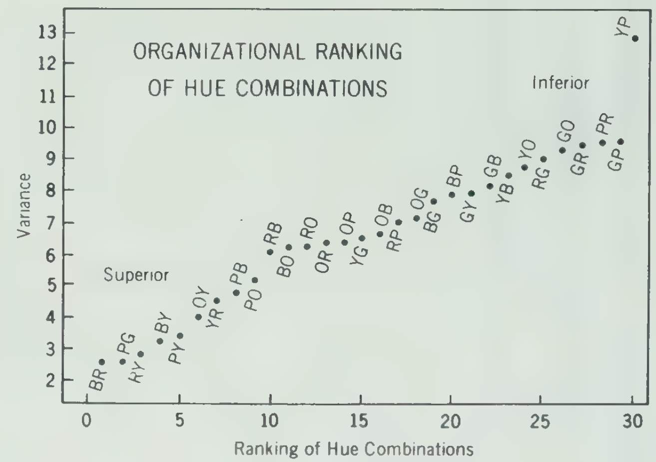
Two possible conclusions can be drawn from the above observations with respect to Koffka and Harrower's findings: (1) Koffka and Harrower's theory is incorrect as their findings are based on a small sample size and (2) lightness difference is the determining factor in producing the organizational superiority of long wavelength test fields on short wavelength backgrounds. The last conclusion is probably more accurate, since a lightness gradient has been demonstrated in other research (Jameson and Hurvich, 1964). As discussed, wavelength does not explain the organizational phenomenon of hue contrast. Selecting

contrasting hues on the basis of long and short wavelengths would not express the relative scaling of contrast desired on a map. Since the only possible explanation of perceived organizational superiority of certain hue combinations lies in the yet unexplainable interaction between symbol and background, hue combinations must be selected on the basis of observable differences, and not on theoretical grounds.

Figure 9 illustrates significantly different hue combinations on the ranked scale of mean scores. For example, green symbols on an orange background (GO) are perceivably different from purple symbols on a yellow background (PY). This graph only attempts to show that a significant difference in contrast exists. The relative scaling of hue combinations with respect to organizing ability is selected from the inset in Figure 9. One notices that purple on yellow has a smaller variance score, indicating stronger "organization," than green on orange. In a mapping situation, a color scheme of purple symbols on a yellow background without a lightness gradient would be a better choice (than green on orange) for the cartographer if his intention is to emphasize the importance of the data.

This study did not attempt to examine all three color dimensions (hue, lightness, and chroma) or other possible graphic variables. While a thorough evaluation of color and graphic symbology is desirable, the present experiment was designed to provide a basis of comparison for further research, and to quantitatively test Koffka and Harrower's hypothesis about the efficiency of hue alone on perceptual "organization". A number of experiments involving hue contrast would be appropriate before tests are conducted on either lightness and chroma contrast or combined tests of all three dimensions of color.





SIGNIFICANTLY DIFFERENT HUE COMBINATIONS ON RANKED SCALE OF MEANS

x Location of hue combination on mean scale.

Statistically significant pairs of hue combinations (at 5% level).

Source: Experimental Data.

Figure 9

The next step in studying hue contrast should be an inspection of subject response to differing number of dots, dot sizes and dot patterns. An extensive study of the perceived effect of other symbol shapes varying in number, size and pattern could also be undertaken.

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APPENDIX A

QUESTIONNAIRE

Age _______________

Sex _______________

Do you have 20/20 vision without corrective lenses? _______________

If you wear glasses, do your lenses correct your vision to 20/20?

____

Do you have experience in using atlases? (check one)

None _______________ Little _______________ Extensive _______________

Are you now taking or have you taken in the past a formal course in cartography (map making)? _______________

If your answer to the above question is yes, did the course cover use of color on maps? _______________

Do you have professional cartographic experience? _______________

Are you now taking or have you taken in the past an art course involving use of color? _______________

APPENDIX B

SAMPLE CHARACTERISTICS

TABLE 1

SEX

Sex	Number by Category
Male	349
Female	251

TABLE 2

AGE

Age	Frequency	Age	Frequency
16	1	34	3
17	20	35	3
18	131	36	5
19	100	37	2
20	81	38	2
21	41	39	2
22	46	40	1
23	27	41	4
24	32	42	1
25	26	43	1
26	11	45	2
27	12	46	4
28	13	47	1
29	4	50	2
30	4	53	1
31	5	56	1
32	4	64	1
33	6		

Source: Research questionnaire.

APPENDIX B

TABLE 3

SUMMARY OF SUBJECTS' EXPERIENCE IN THE USE OF COLOR

Atlas Experience			Cartography Course	Studied Color on Maps	Professional Cartographic Experience	Art Course (Studied Color)
None	Little	Extensive				
45	489	66	90	42	15	119

Source: Research questionnaire.

Appendix C

Sample Hues

APPENDIX D

MUNSELL NOTATION AND DOMINANT WAVELENGTH

Hue	Munsell Notation Hue No.	Munsell Notation Hue Symbol	Dominant Wavelength (millimicrons)
Red	5.0	5R 7/6	604
Yellow-Red	15.0	5YR 7/6	586
Yellow	25.0	5Y 7/6	576
Green	45.0	5G 7/6	516
Blue	65.0	5B 7/6	485.5
Purple	85.0	5P 7/6	562.5

Source: Munsell Book of Color, 1929.

APPENDIX E

EXPERIMENTAL DATA: OBSERVATIONS, MEAN AND VARIANCE

	BG	BY	BO	BR	BP	GB	GY	GO	GR	GP
	15	10	11	12	10	08	15	12	12	10
	15	10	15	12	15	10	10	12	15	12
	12	12	15	12	20	10	10	10	15	16
	11	12	15	12	15	12	14	18	09	12
	10	10	10	10	12	10	15	15	15	10
	10	10	14	13	12	10	10	15	10	20
	12	12	10	10	10	10	10	10	10	12
	20	12	13	10	12	12	08	10	11	11
	10	13	15	14	10	12	12	15	18	12
	08	12	12	15	10	11	15	12	09	12
	10	08	11	12	12	10	12	12	14	20
	10	15	14	12	10	09	12	12	10	10
	12	14	12	12	08	14	11	14	10	11
	12	12	12	14	10	12	12	12	10	10
	15	11	12	10	10	12	10	15	10	15
	10	12	10	12	12	12	12	15	14	12
	10	10	14	10	15	18	10	15	14	12
	10	10	10	15	09	20	20	17	12	12
	12	12	15	10	12	12	15	20	20	10
	15	15	20	12	09	10	15	20	12	16
MEAN	11.95	11.60	13.00	11.95	11.65	11.70	12.40	14.05	12.50	12.75
STD. ERROR	.626	.400	.562	.366	.629	.641	.630	.679	.682	.688
STD. DEV	2.800	1.789	2.513	1.638	2.815	2.867	2.817	3.039	3.052	3.076
VARIANCE	7.839	3.200	6.316	2.682	7.924	8.221	7.837	9.208	9.316	9.461

Appendix E contd.

	YB	YG	YO	YR	YP	OB	OG	OY	OR	OP
	12	13	15	11	12	10	15	14	10	10
	10	16	15	12	10	11	20	12	12	15
	20	12	20	12	15	12	10	12	10	12
	12	20	11	16	13	12	12	10	12	13
	10	12	12	10	10	15	12	15	13	20
	10	11	14	10	11	15	10	12	12	10
	12	12	11	15	20	15	12	15	11	15
	12	12	15	15	10	10	11	15	15	11
	13	08	12	12	20	12	10	12	10	12
	12	10	13	10	12	12	12	10	14	15
	12	10	15	15	15	12	15	15	11	12
	15	11	10	15	13	14	12	10	20	12
	10	11	10	10	09	15	10	10	14	10
	12	15	12	12	12	15	10	12	16	15
	14	12	10	15	20	20	10	12	13	12
	12	12	10	12	10	10	16	09	12	10
	11	10	12	12	12	10	10	13	12	15
	10	11	15	10	16	10	12	12	10	10
	20	10	12	15	11	12	10	10	10	12
	10	12	20	11	09	15	10	15	10	12
MEAN	12.45	12.00	13.20	12.50	13.00	12.85	11.95	12.25	12.35	12.65
STD. ERROR	.655	.576	.663	.478	.801	.582	.596	.452	.568	.568
STD. DEV	2.929	2.575	2.966	2.140	3.584	2.601	2.665	2.023	2.540	2.540
VARIANCE	8.576	6.632	8.800	4.58	12.842	6.766	7.103	4.092	6.450	6.450

Appendix E contd

	RB	RG	RY	RO	RP	PB	PG	PY	PO	PR
	12	15	10	12	09	15	12	09	12	12
	10	12	13	15	12	10	12	13	15	14
	12	12	10	14	12	13	12	11	14	10
	12	10	12	12	09	15	15	10	13	13
	15	10	15	15	20	15	15	10	12	11
	12	12	12	11	09	13	10	10	14	14
	20	15	10	15	10	15	12	10	14	10
	10	13	09	12	15	08	12	10	15	10
	11	15	12	11	12	12	11	12	10	10
	12	10	10	12	12	15	15	10	14	17
	12	10	12	20	12	10	10	14	20	14
	13	11	10	10	11	13	12	10	15	12
	09	14	10	11	14	14	12	09	15	12
	12	20	12	10	10	14	12	10	15	20
	15	15	15	12	10	12	12	13	18	15
	10	20	12	12	15	15	09	12	13	12
	15	12	10	10	12	11	13	16	12	12
	14	12	10	12	10	15	12	10	12	10
	15	15	10	09	10	10	11	12	12	20
	12	10	12	12	12	11	10	10	12	15
MEAN	12.65	13.15	11.30	12.40	11.80	12.80	11.95	11.05	13.85	13.15
STD. ERROR	.559	.674	.378	.564	.592	.490	.366	.407	.509	.685
STD. DEV	2.498	3.014	1.689	2.521	2.648	2.191	1.638	1.820	2.277	3.066
VARIANCE	6.239	9.082	2.853	6.358	7.011	4.800	2.682	3.313	5.187	9.397